Field Tests of Dedicated CNG Vehicles in Korea

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1. Introduction

Dependence on oil in KOREA is increasing annually(from 53.8% in 1990 to 54.52% in 1998) and dependence of energy on oversea has been rising steadily. Therefore a concern of energy security has been brought up, because dependence of oil on the Middle East is increasing continuously. Especially dependence on oil for transportation energy is close to 100% and most of oil is unevenly distributed in the Middle East. Hence, if proved natural gas reserves of which is 22 year longer than oil and which is evenly distributed a worldwide is used in car fuel, energy will be preserved in stability.
And the number of vehicles in KOREA have exceed 10.51million in 1999 from 40 thousand in 1964 with the rise of national income and it is the increase of 263 times after 35 years. And especially the number of passenger cars has increased more than 358 times rapidly. And the problem of environmental pollution by exhaust gas of cars will be serious as time goes on because the number of vehicles will increase up to 14 million in 2000. Pollutants from vehicle are different slightly by the components of fuel but gasoline and gas fuel exhaust CO, HC, Nox and SOx in a very small amount and diesel exhaust PM besides. Because pollutants of transportation(2,194,318 ton) account for 50.2% of total air pollutants(1997, 4,364,723 ton), air pollution by transportation in KOREA is a very serious concern. And pollutants of vehicles(1997, 1,794,647 ton) account for 41.1% of total air pollutant. And comparing with pollutant of gasoline(include LPG)which account for 35%(The number of vehicles : 69.3%) of total vehicle pollutant and diesel which account for 65%(The number of vehicle : 30.7%) of total vehicles pollutant, pollution level of diesel is very high. Especially it is reported that pollutant of diesel such as large buses and trucks account for 52.0%(the number of vehicles : 5%) of total amount. And because it is invested that a pollution level of Seoul which account for 77.1% of the whole is highest and Deagu, Kwangju, Deajun out of all metropolis occupy up to 50%, There is a need for reduction of vehicle pollutants in the metropolis. Especially the world Cup will be held together in Korea and Japan at 2002. So, 5,000 NGV buses will be propagated till 2002 in the cities where the World Cup is held to bring clean air into relief in Korea. Therefore a fleet of NGVs(passenger cars and buses) were operated on the field test to verify safety, superiority and low emission before real propagation.

2. Field tests of NGV(passenger car) and Natural Gas Bus

2.1 NGV(Passenger Car)

The field test of NGV(passenger car) was carried out for the first time in Korea with cars(Kia : 3 Sportage, Deawoo : 3 Cielo, Hyundai : 3 Accent) of 3 car makers in Korea by support of Ministry of Environment and event of it was held at Oct.,1996. But the

field test could not be carried out because there was no regulation to install CNG refueling station at that time in Korea. But after the regulation was enacted at Dec., 1996 and operation of CNG refueling station was approved at Apr., 1997, the field test could be carried out from Jan., 1998 to Dec., 1998,

Fig. 1 Event for the field test of NGV(passenger car)

Fig. 2 NGV(passenger car) on the field test(1998)

Respective 3 cars out of Sportage(Kia), Cielo(Deawoo) and Accent(Hyundai) which were in production were converted to NGV and the cars was operated in the field test. Specifications of respective cars are listed in Table 1.

Table 1. Specifications of Natural Gas Vehicles

	Sportage	Accent	Cielo
Engine	FEDI	á-II	1.6l SOHC CNG
Compression Ratio	10.9	12.6	10.8
Fuel Tank Capacity(l)	83	95.1	75
Materials of fuel tank	Al+FRP	Fully Composite	Fully Composite
Refueling pressure(bar)	200	200	200
Weight(kg)	1,520	970	1,103.5

Unlike gasoline, natural gas is supplied into a combustion chamber in gas phase and it makes decrease in the performance of vehicles by the reduction of volume efficiency. Therefore a counterplan for this problem should be considered. And because gas is affected by temperature and pressure, it must be compensated for them. To optimize natural gas engine, camshaft, compression ratio and tumble ratio were modified in hardware and ignition timing, A/F ratio and injection in software. And catalytic converter for natural gas was developed for the reduction of exhaust gas.

Table 2. Comparison of Gasoline Vehicle and Natural Gas Vehicle

Item	Gasoline Vehicle	Natural Gas Vehicle
Car	Sportage Gasoline	Sportage CNG
Displacement(cc)	1998	1998
Compression Ratio	9.2	10.9
Refueling pressure(bar)	-	250
Weight(kg)	1,450	1,520
Fuel Supply	MPI	MPI
Injection Pressure(bar)	3	7
Emission control device	3-way catalytic converter	Catalytic converter for CNG

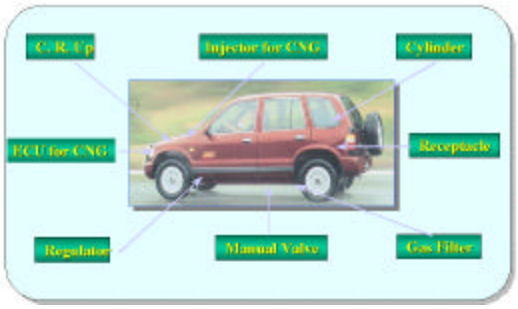


Fig. 3 Main converted parts of NGV

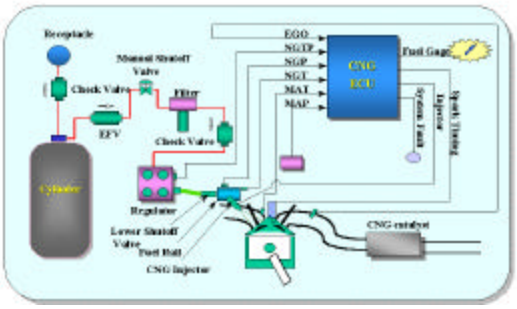


Fig. 4 Fuel system of NGV

Main converted parts and fuel system of Natural Gas Vehicle are shown in Figures 3 and 4. CNG refueling station(flow rate : 29 scfm, gas capacity : 100)which was installed in KOGAS on Oct., 1996 has been refueling gas to vehicles in the field test. And because it was purpose of this field test to demonstrate excellency, air cleanness and safety of Natural Gas Vehicles and to publicize them to the public, the public had driven NGV himself and evaluated advantage and disadvantage of NGV. The NGVs on the field test were operated mainly for business use and the drivers have recorded mileage and refueling quantity during the field test. And fuel consumption was estimeted by mileage and refueling quantity. The mileage of 9 NGVs was 164,000 km and the mean mileage of one NGV was 18,176 km during the period of Jan., 1998 to Dec., 1998.

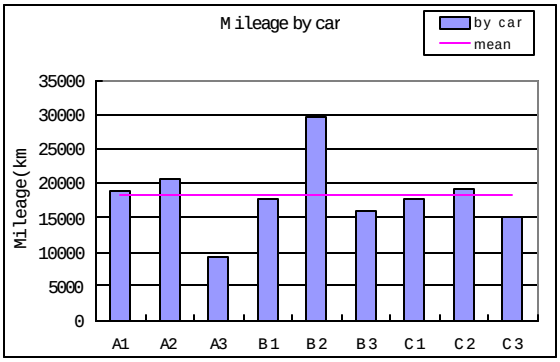


Fig. 5 Mileage by car

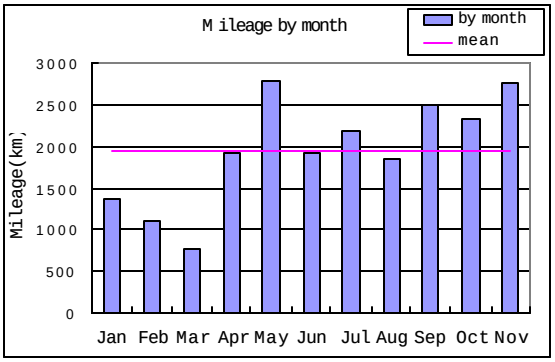


Fig. 6 Mileage by month

The mean fuel consumption of 9 NGVs was 15.88 km/kg and it is equivalent to 10.11 km/ in gasoline vehicle. Therefore as compared with 11.4km/ of gasoline vehicle, the fuel consumption of NGV is almost equal with that gasoline vehicle.

Table 3. Mean fuel consumption

Km/kg	Km/	Km/ (in gasoline equivalent litre)
15.88	12.76	10.11

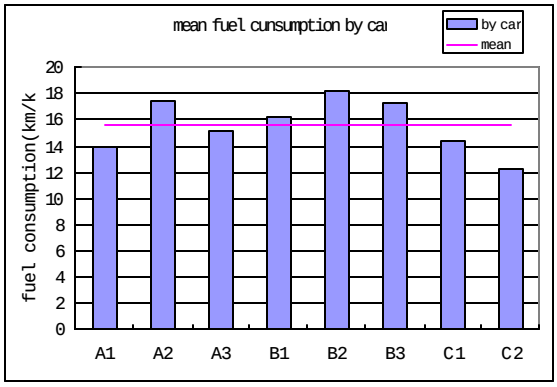


Fig. 7 Mean fuel consumption by car

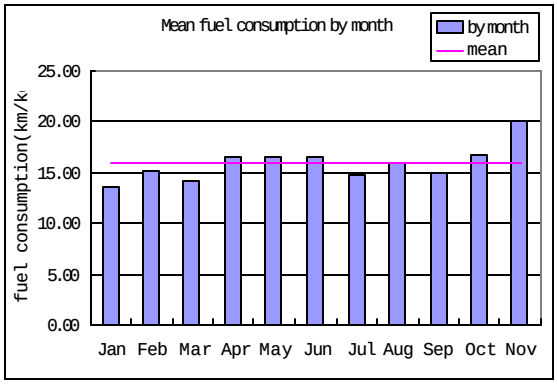


Fig. 8 Mean fuel consumption by month

And emission of NGV on the field test was measured. Table 4. shows comparision of emission between NGV and other fuel vehicles in the CVS-75 mode. CO is 36% lower than that of gasoline ,HC is 88%, 80% lower than that of gasoline/diesel and NOx is 64%, 96% lower than that of gasoline/diesel respectively.

Table 4. Emission of Natural Gas Vehicle

Type of car	Fuel	Emission(g/km : CVS-75 mode)				Fuel consumption (km/)
		CO	HC	NOx	Aldehyde	
Accent	CNG	0.48	0.01 (NM)	0.02	0.004	13.9
	Gasoline	1.21	0.15	0.13	-	16.2

Cielo	CNG	0.60	0.02 (NM)	0.07	-	12.0
	Gasoline	0.31	0.08	0.05	-	13.6
Sportage	CNG	0.755	0.018 (NM)	0.05	-	10.4
	Gasoline	0.28	0.08	1.25	-	11.5

And because the fuel consumption of Table 3 was measured in the field test and that of Table 4 was measured in a chassis dynamometer in the CVS-75 mode, both value are different.

1) Natural Gas Bus

Together with gas companies(Kogas, Samchully), car makers(Deawoo, Hyundai) and transportation companies (kyungwon, samhwan) performed the field test of Natural Gas Bus in the management of Minisry of Department. Samhwan, transportation company of Incheon city, operated 2 NGVs which Hyundai has converted as urban buses. Kyunwon, transportation company of Ansan city, operated one of 2 NGVs which Deawoo has conveted as a seat bus and KOGAS operated the other for business use. As shown in Fig. 9, the field test in Incheon was started at July 27, 1998 and the NGV buses were operated to a distance of 92 km 6 times a day. The field test in Ansan was started at September 16, 1998 and the seat bus of Kyunwon was operated to a distance of 84 km 5 times a day. Natural Gas Buses in Ansan were fueled from the CNG refueling station of KOGAS and those of Incheon were fueled from that of Samcholly.

Fig. 9 Event of field test for Natural Gas Buses

Table 5 represents the specifications of Natural Gas Buses on the field test.

Table 5. Specifications of Natural Gas Buses

The type of car	D6AB(Hyundai)	BH116(Deawoo)	BS106(Deawoo)
Operation Company	Samwhyan	KOGAS	Kyungwon
Type	Standing bus	Seat bus	Seat bus
Capacity	67	40	40

Engine	Model Displacement(cc) Max. power(ps/rpm) Max. torque(kg.m/rpm) Fuel control system	D6AB 11,149 270/2200 100/1400 Full auto elec.	GE12TI 11,051 280/2200 110/1300 Full auto elec.	GE12TI 11,051 280/2200 110/1300 Full auto elec.
Transmission		M10S5	K1205A(5D.D)	K1005A(5D.D)
GVW(kg)		14,465	14,450	13,005
Max. speed(km/h)		130	108	108
Gradability(tanè)		0.390	0.385	0.385
Fuel tank	Type Max. pressure(psi) Size & Quantity	NGV-3600 13”×70”: 4 13”×50”: 2	NGV-3600 13”×60”: 8	NGV-3600 13”×60”: 6
	Capacity(/)	650/165	750/220	562/160

Fig 10 shows schematic inside structure of Hyundai Natural Gas Bus.

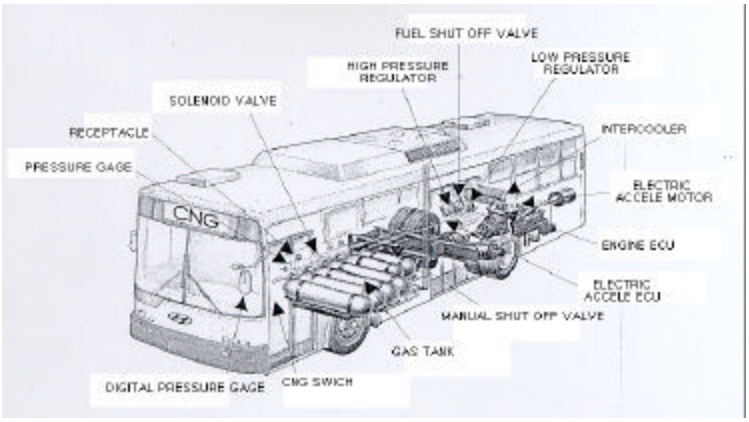


Fig. 10 Schematic inside structure of Natural Gas Bus

As field test of NGV(passenger), mileage and fuel consumption were measured in this field test. As shown in Table 6, total mileage of 4 Natural Gas Buses is 139,309 km till March 21, 1999 and mean fuel consumption is 2.2 km/ , 2.7 km/kg and it is equivalent to 1.9 km/ in diesel vehicle. Therefore as compared with fuel consumption of diesel vehicle, NGV is almost equal to diesel vehicle.

Table 6. Mileage and fuel consumption of Natural Gas Bus on the field test

		KOGAS	Kyungwon	Samhwan (3166)	Samhwan (3167)
		1998.9.15 1999.3.18	1998.9.18 1999.3.13	1998.8.15 1999.3.21	1998.8.15 1999.3.21
Mileage(km)		8,265	66,345	29,810	34,889
Fuel consumption	Km/	2.4	2.2	2.0	2.1
	Km/kg	3.0	2.8	2.5	2.6
	Km/ diesel	2.1	2.0	1.8	1.8

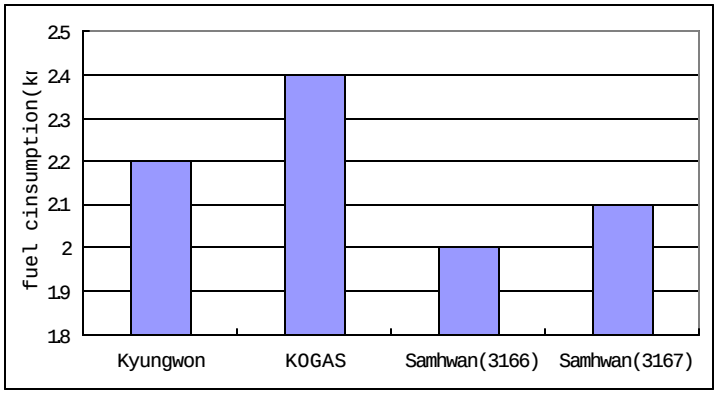


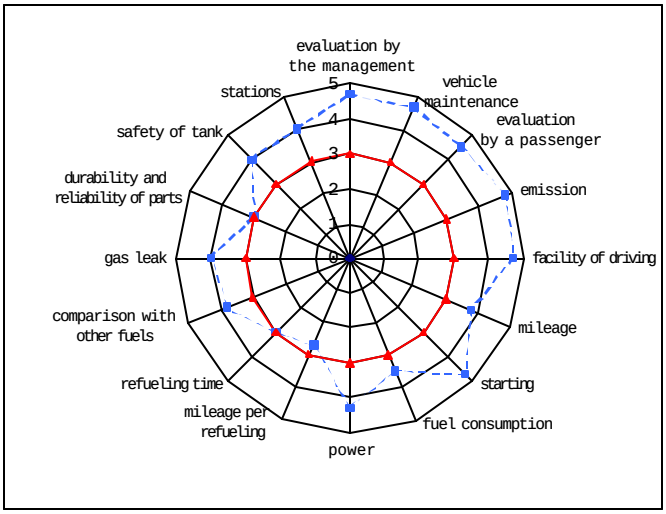
Fig. 11 Fuel consumption by NGV

2) Interim evaluation of NGV(Bus) field test

Interim evaluation of the Natural Gas Buses was carried out at March 17, 1999. It's purpose was to analyze results and check problems on the field test. Specialists of NGV took the task for objective evaluation(perfect score : 5, diesel : 3). The evaluators consisted of 3 officers, 4 Natural Gas Bus specialists and 4 CNG refueling station specialists. 3 items – operating condition, vehicle performance, safety - were evaluated and each items were divided into several branches. As shown in Table 7 and Fig 12, mileage per refueling was very short because fuel was supplied in gas phase. And improvement of parts is demanded too. But these problems will can be solved with a rasing refueling pressure(200bar 250,300bar), improvement of parts. And it was evaluated that NGV is superior to diesel vehicle in performance, maintenance and emission.

Table 7. Interim evaluation of Natural Gas Bus on the field test

Evaluation items		Evaluation results
Operation of Bus	Evaluation by management	4.7
	Vehicle maintenance	4.7
	Evaluation by a passenger	4.5
Vehicle performance	Emission	4.8
	Facility of driving	4.7
	Mileage	3.8
	Starting	4.7
	Fuel consumption	3.5
	Power	4.3
	Mileage per refueling	2.7
	Refueling time	3.0
	Comparison with other fuels	3.8
Safety	Gas leak	4.0
	Durability and reliability of parts	3.0
		4.0
	Safety of tank	4.0
	Stations	



1	2	3	4	5
Worst	Worse	Moderate	Better	Best

Fig. 12 Interim evaluation of Natural Gas Bus on the field test

NGV is similar to diesel vehicle in general performance but passing acceleration performance falls off because of characteristics of gas engine. Engine oil exchange period of NGV may be longer than diesel vehicle. And as compared NGV with diesel vehicle, NOx, HC is reduced to about 30~40 % of diesel vehicle and PM is not emitted at all in NGV. Because noise and vibration is lower than diesel vehicle, some passengers wait for Natural Gas Bus to take the bus. Table 8 shows comparison of emission of NGV and diesel vehicle.

Table 8. Emission of Diesel Bus and Natural Gas Bus
(unit : g/kwh)

Section	HC	NOx	CO	PM
Diesel bus(A)	0.50	7.15	1.25	0.29
NG bus(B) (w/o catalyst)	0.15	2.64	1.59	0
B/A(%)	30	37	127	-

- Certificated data(National Institute of Environmental Research Motor Vehicle Emission Research Laboratory)

And only a trifling defect occurred during the field test of NGV(passenger, bus). Therefore we got satisfied with safety results. Similarly, there was no problem in operating of the CNG refueling station.

3) Propagation plan of NGV in Korea

Natural Gas bus service will be started after field tests of NGV in Incheon and Ansan. 15 NGVs and 3 refueling stations will be operated in the field test and 20,000 urban buses of metropolitan and megalopolis which pollution is excessive will be successively

replaced by NGV from the year of 2000 year. Especially about 5,000 NGVs and 100 refueling stations will be propagated above all in holding cities of 2002 worldcup. Budget of about 164.6 millions dollar will be invested in 8 cities which pollution is excessive out of 10 holding cities.

Table 9. Propagation plan of Natural Gas Bus and refueling station (US$ Thousand)

Item	Total	2000	2001	2002	2003 2007
CNG Bus Refueling station	20,000(421,941) 210(124,051)	1,500(31,646) 30(17,722)	1,650(34,810) 33(19,494)	1,850(39,030) 37(21,857)	15,000(316,456) 110(64,979)

* 1. purchase price of NGV(inremental price) : support of $21,097 per vehicle(aid of 50%, financing of 50%)

* 2. installation price of CNG refueling satation : support of $590,717 per station by financing

Table 10. Propagation plan of Natural Gas Bus in 8 cities which hold Worldcup

Items		Total	2000	2001	2002
Total	Bus	5,000(105,485)	1,500(31,646)	1,650(34,810)	1,850(39,030)
	Stations	100(59,072)	30(17,722)	33(19,494)	37(21,857)
Seoul	Bus	2,600(54,852)	600(12,658)	1,000(21,097)	1,000(21,097)
	Stations	52(30,717)	12(7,089)	20(11,814)	20(11,814)
Pusan	Bus	850(17,932)	300(6,329)	250(5,274)	300(6,329)
	Stations	17(10,043)	6(3,544)	5(2,954)	6(3,544)
Teagu	Bus	400(8,439)	100(2,110)	100(2,110)	200(4,219)
	Stations	8(4,726)	2(1,181)	2(1,181)	4(2,363)
Incheon	Bus	300(6,329)	100(2,110)	100(2,110)	100(2,110)
	Stations	6(3,544)	2(1,181)	2(1,181)	2(1,181)
Kwangju	Bus	200(4,219)	100(2,110)	50(1,055)	50(1,055)
	Stations	4(2,363)	2(1,181)	1(591)	1(591)
Teajon	Bus	250(4,219)	100(2,110)	50(1,055)	100(2,110)
	Stations	5(2,954)	2(1,181)	1(591)	2(1,181)
Ulsan	Bus	200(4,219)	100(2,110)	50(1,055)	50(1,055)
	Stations	4(2,363)	2(1,181)	1(591)	1(591)
Suwon	Bus	200(4,219)	100(2,110)	50(1,055)	50(1,055)
	Stations	4(2,363)	2(1,181)	1(591)	1(591)

* ( ) : Budget (US$ Thousand)

(1) Problems and policy for propagation of Natural Gas Bus in KOREA

Cost required for the NGV propagation is mostly fixed ones due to installation of refueling station and price of natural gas. Invested cost of the first stage is higher than that of diesel vehicle because demand of NGV is not enough in the first stage of propagation. Because this reason makes private class avoid investment of the first stage and this is a big obstacle in the propagation, it needs various incentives of government to pay back invested cost of the first stage in early stage. The Government and self-governing government are planning to assist such as reduction of taxes and control of bus service route to pay back invested cost of the first stage in early stage. Budget of 164.6 millions dollars will be supported to reduce price of natural gas, cost for installing of refueling station and incremental cost of NGV for 5,000 NGVs propagation from year 2000 to 2002. And the Government has a plan to propagate NGV according to a

principle of the market economy with economic incentive and obligatory purchage.

Table 11. Propagation strategy of Natural Gas Bus

Items	The first stage (2000~2002, 5,000)	The real stage (2003~2007, 15,000)
Strategy	- priority in the economical incentives • support of incremental price of vehcles, installating price of stations and taxation •fixation of NG price for transportation low than diesel price	- enforceable of incentives and compulsory purchase system side by side • impeling compulsive replacement of diesel buses in the city of serious pollution (reinforcement of regulation) • as consider trend of propagation, the control of incentives and continuously support
Budget	164,557 thousand dollar	381,435 thousand dollar

The Government will support aid of 50% and financing of 50% to bus companies for incremental cost of Natural Gas Bus. And the Government have a plan which natural gas price is lower than that of diesel and to reduce custom duty and corporation tax to actively propagate Natural Gas Bus. There is a plan to support all of installation cost by financing, control gas price to assure profits of gas selling to companies and reduce special excise taxes in order to retrieve investment cost in early stage.

Table 12. Plan of support for propagation of Natural Gas Bus

Items	Bus companys	Station company
Supporting aim	Supporting incremental costs of Bus price (US$ 21,097~25,316/bus)	Guarantee of reasonable profit of gas selling For keeping of equipment investment
Plan for support	Financial support - aid of 50% for incremental Bus price - financing of 50% for incremental Bus price	Financial support - low-interest loan of equipment investment
	As fix lower NG price than diesel, grant of substantially benefits for operation of bus	Adjustment of fuel price - Adjusting profit of gas wholesale price for transfortation at less than 1/3 of it for industry - adjustment of profit of retail price up-ward
	Support of taxation - reduction of custom duty and corporation tax exemption of a surtax and acquisition tax for stabilization of Bus price	Support of taxation - Exemption of special excise tax(\32/)

3. Results

Research of NGV in Korea was started with "Feasibility study for the development of CNG vehicle & Gas engine" in 1991 and possibility of practical use in Korea was affirmed by "Development of packaged type CNG refueling system", "Development of compressed natural gas fuel cylinder for vehicle", "Development of natural gas engine and vehicle". Field tests of NGV(passenger car and bus) was enforced base on these studies.

1) It is ascertained that performance of NGV is similar to that of gasoline and diesel from this field test.
2) NGV is superior to other fuel in reduction of pollution.
3) Practical use of NGV in Korea was ascertained by the field tests
4) It is under study to extend mileage per refueling and to use NGV as a bus on a regular route and in airport to solve shortness of mileage.
5) There is a plan to develop LNG vehicle and LCNG refueling station which mileage per refueling are 4 times as much as that CNG vehicle

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